Table 6. Material balance for atmospheric CO_2 (values in Gt C per year)

	Source Fossil	Biogenic	Soil derived	Increase atmosphere	Sink Oceans	Unexplained surplus
Case I	5	2.3	2.0	2.8	2.2	4.3
Case II	5	1.6	1.3	2.8	2.6	2.4
Case III	5	1.1	1.0	2.8	3.3	1.0

Case I: data as derived from table 3 and 4 (centers of estimates); case II: biogenic and soil release reduced by 30%, oceanic uptake increase by 20% ; case III: biogenic and soil release reduced by 50%, oceanic uptake increased by 50%.

Assuming the lower estimates are correct, a source - sink problem does not exist. This is the situation described by the box diffusion model (Oeschger et al., 1975, 1980), which, regarding the range of uncertainties of some of the model parameters, can account for the atmospheric CO_2 increase under consideration of a biogenic input in the order of $\pm 10\%$ of the fossil one. If, on the other hand, one considers the upper values for biogenic and soil C release then there is a real source - sink problem that cannot be explained by any of the models we are familiar with.

Taking the centers of estimates (see table 6, case I) the biota clearly act as a source for atmospheric CO_2 to such an extent that the resulting surplus must be counterbalanced by some yet unknown sink(s), if the ocean uptake capacity is assumed to remain unchanged.

Recently, however, several suggestions have been made resulting both in a lower input of biogenic C to the atmosphere and an enhanced uptake of C by the oceans. Seiler and Crutzen (1980), in analyzing phytomass burning, estimated that incomplete combustion leads to a large fraction of relatively stable, reduced C compounds (e.g., charcoal) which do not reach the atmosphere within the considered time range. A process with a similar effect has been proposed by Lieth (personal communication). Following vegetation changes by man's impact, erosion may start or increase leading to an enhanced river discharge of soil C into the oceans. Taking into account both effects, we may reduce the values for phytomass- and humus-derived CO_2 input each by 30% (case II) and by 50% (case III), respectively. A possible increase of the C uptake capacity of the oceans has been suggested by considering downwelling of polar surface waters (Björkström, 1979a; Hoffert et al., 1979) and additional dissolution of $CaCO_3$ (Keeling and Bacastow, 1977, Wollast et al., 1978). We summarize both effects again in table 6 by assuming an oceanic uptake increased by 20% (case II) and by 50% (case III), respectively.

In the intermediate case (II) 2.4 Gt C per year of atmospheric C input remain unbalanced whereas this figure is reduced to 1 Gt C per year in case III. In that case the source - sink problem is reduced to a large extent, however a lot of detailed work has to be done before a sufficient understanding of the atmosphere - biosphere - ocean system is obtained.

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The effect of the atmosphere-biosphere exchange on the global carbon cycle

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The earth's land vegetation and soils currently comprise 2000–3000 $\times 10^{15}$ g of organic C, roughly 3–4 times the amount stored in atmospheric CO_2 (table 1). If these reservoirs lose or gain only 1‰ of their organic C, the result will be a net input of CO_2 to, or a net withdrawal from, the atmosphere of 2–3×10^{15} g, equivalent to 40–60% of the current annual anthropogenic CO_2 production from the burning of fossil fuels. Even an annual net transfer of only one tenth of this size, or 0.2–0.3 $\times 10^{15}$ g, will represent a quantity anything but negligible if one attempts to model the global carbon cycle. This demonstrates the high short-term sensitivity of the atmospheric CO_2-budget to natural or anthropogenic changes in the terrestrial biota's C pool.

Models of the global carbon cycle generally conclude that the amount of organic C stored in land vegetation and soils is, presently, either in a steady state or is slightly increasing (Keeling, 1973b; Bacastow and Keeling, 1973; Oeschger et al., 1975; Keeling and Bacastow, 1977; Broecker et al., 1978; Siegenthaler and Oeschger, 1978; Björkström, 1979). Otherwise, the distribution of fossil fuel CO_2 between the atmosphere, shallow and deep oceans cannot be computed in accordance with empirical observations such as the vertical distribution of ^{14}C and ^{3}H in the ocean. In contrast, workers involved in global vegetation science are convinced that, as a result of the overall destructive impact of man in the world's ecosystems, especially in the tropics, vegetation and soils are now losing C rather than gaining it on a worldwide scale. According to this, the terrestrial biota is a net source rather than a net sink of C (Woodwell and Houghton, 1977; Bolin, 1977; Woodwell et al., 1978; Woodwell, 1978; Wong, 1978a).

If true, the latter perspective would bear far-reaching consequences: The present annual net increase of atmospheric CO_2 is about 3×10^{15} g of C, some 60% of the man-made input from fossil fuel. Thus, 40% of the annual input is transported to other reservoirs, such as the ocean, if fossil fuel is indeed the only source. Assuming, however, that there are additional sources, the percentage of the annual input remaining airborne must decrease, as demonstrated by an arbitrary example: if land vegetation and soils annually lost 4×10^{15} g of C to the atmosphere, the total input would be 5×10^{15} g from fossil fuel plus 4×10^{15} g from nonfossil sources, or 9×10^{15} g. Given an atmospheric increase of 3×10^{15} g, only 33% of the total input rather than 60% would remain airborne, and 67% instead of 40% would be transferred to other reservoirs. The mechanisms withdrawing man-made CO_2 from the atmosphere would be more efficient. Either the known sinks would operate more effectively or additional, previously unknown, sinks would have to be postulated.

The implications of such a case for the future atmospheric CO_2 increase are discussed in further detail in another paper (Hampicke, 1980). Whether or not energy strategies, aiming at reducing the risks of man-made climatic changes could start from more favourable conditions if the airborne fraction should prove to be lower than roughly 0.6, depends on a number of parameters. Generally, it can be said that a reliable projection of future atmospheric CO_2 levels requires that the role of the terrestrial biota be sufficiently understood.

Unfortunately, this reservoir is the most heterogenous of all. The organic C content varies from a few g/m² in deserts to about 30,000 g/m² in most forests to more than 500,000 g/m² in some peat bogs (table 2). The residence time of a C atom in the terrestrial biota ranges from a few seconds - if it is used for photorespiration soon after photosynthesis - to several thousand years - if it happens to become humified in soil, peat or lake sediments -, before it is returned to the atmosphere. The annual exchange of C between atmosphere and land biota, as caused by photosynthesis and respiration, ranges from close to zero in deserts to several thousand g/m² in highly productive

Table 1. Estimates of world organic C inventory in land vegetation and soils

	Vegetation (10^{15} g C)	Soil organic matter (10^{15} g C)
Rodin, Bazilevich and Rozow (1975)	1,081[a])	
Olson et al. (1978)	1,050[a])	
Bazilevich (1974)		1,200
Whittaker and Likens (1975)	827[b])	
Baes et al. (1977)	600	1,000
Olson et al. (1978)	557	
Ajtay et al. (1979)	560	1,636
Bohn (1976)		2,946
Schlesinger (1979)		1,515
Buringh (1979)		2,014[a])
Buringh (1979)		1,477
For comparison: atmosphere in 1977	702	

[a] Potential inventory, prior to human influence. [b] In approximately 1950. All other values apply to the mid-1970's.

Table 2. Organic C in selected ecosystems

Vegetation type	Average phytomass and litter[a] (g/m² C)	Average soil organic matter to 1 m depth[b] (g/m² C)	Total, g/m² C Average	Estimated range[c]
Extreme deserts	30	170	200	< 100
Tropical grassland	1,100	4,500	5,600	3,000- 10,000
Desert scrub	600	5,800	6,400	
Cultivated land, temperate	100	7,900	8,000	5,000- 30,000
Chaparral, maquis, etc.	3,400	7,000	10,400	5,000- 20,000
Tropical dry forest	7,000	7,000	14,000	
Temperate moist grassland	1,200	18,900	20,100	10,000- 30,000
Low Arctic tundra	3,600	20,400	24,000	
Tropical lowland moist forest	19,000	9,800	27,800	15,000-200,000[d]
Temperate mixed forest	15,000	13,400	28,400	
Boreal closed forest	13,200	20,600	33,800	
Tropical montane forest	15,000	28,700	43,700	
Unexploited peatland	2,000	110,000	112,000	> 500,000[e]
For comparison: Atmosphere, averaged over whole earth			1,375	
Atmosphere, averaged over continents			4,680	

[a] After Ajtay et al., 1979, slightly modified. [b] After Schlesinger, 1979, slightly modified. [c] Own estimates. [d] Values above 50,000 g/m² only in coastal Pacific coniferous forests. [e] Including organic C below 1 m depth.

ecosystems. As shown in table 3, the annual net exchange – the difference between total annual photosynthesis and total annual respiration plus fire – can also amount to many hundred g/m² of C for natural reasons, and to several thousand g/m² for anthropogenic reasons.

Unless averaged over long periods of time and over large areas, no ecosystem on the land is in a steady state; there are net exchanges of C to and from the atmosphere everywhere. A well-known example is the seasonal fluctuation of photosynthesis and respiration in the temperate regions of the northern hemisphere, causing a pronounced oscillation of atmospheric CO_2 with an amplitude of more than 5 ppm at Mauna Loa (Hawaii) (Hall et al., 1975; Keeling et al., 1976b). To assess what the global average might be of many different net exchange processes, natural and man-made, in thousands of different terrestrial ecosystems all over the world is, obviously, an enormous task. In the following, I briefly summarize the conclusions that are possible from the direct observation of the world's land vegetation and from the evaluation of ecological, agricultural, demographic and other kinds of data.

Population increase and need for new arable land

The population of the world's tropical and subtropical countries (approximately within 30 °N and 30 °S) is increasing by 2.4% per year. Because intensifying cropping is impossible in many areas due to lack of fertilizers, pesticides and irrigation water, there must be an annual increase of cropland of at least 2% in order to feed these additional people, corresponding to $120–180 \times 10^9$ m²/year. This land is partly reclaimed from forested areas and involves fire-clearance of the vegetation with subsequent high net transfers of C to the atmosphere. In other areas, less phytomass has to be removed. Frequently, the vegetation is only partly mineralized to CO_2 while boles, roots and some stems are left in the field. The average phytomass in the entire tropics, including forested and nonforested areas (together approximately 40×10^{12} m² excluding deserts) contains about 6800 g/m² of organic C (Hampicke 1979c, calculated from Ajtay et al., 1979). Assuming that, on the average, half of this quantity, or 3400 g/m² of C, is released by fire-clearance for domestic agriculture, an overestimate of the total amount is very unlikely, for this amounts to less than 20% of the C in the phytomass of mature tropical rain forests. The total net release is then in the order of 0.5×10^{15} g/year.

Commercial rain forest clearance

In addition to the reclamation of land for domestic agriculture, often carried out on a subsistence level, largescale commercial clearance for the recovery of timber and the creation of pastures is increasing quickly, most particularly in South America (Goodland and Irwin, 1975) and South East Asia (Brünig, 1977; Ranjitsinh, 1979). Although available figures are very unreliable, an area of 50×10^9 m² cleared annually might be regarded as a minimum. Assuming an annual net mineralization of 10,000 g/m² of C – only 50% of the phytomass of an average tropical rain forest – there results an annual net transfer to the atmosphere of 0.5×10^{15} g of C.

Decrease in soil organic matter

Cropping formerly uncropped soils almost invariably results in a decline of soil organic matter (Buringh, 1979); temperate and tropical soils differ in the speed of humus decay rather than in the total quantity affected. Unless cropping is carried out in an exceptionally careful way, implying, among other things, the maintenance of shade (Nye and Greenland, 1960), the topsoil in tropical cropland contains only 30–70% of its original organic matter (Young, 1976). The C lost amounts to roughly 3000–7000 g/m², which implies a total annual loss of $0.3–1.0 \times 10^{15}$ g of C (see also Buringh, 1979; Schlesinger, 1977, 1979).

Long-term degradation of vegetation

If subject to continuous pressure from human exploitation, the phytomass in ecosystems may decrease

Table 3. Net accumulation and net loss of C in selected ecosystems for natural and man-made reasons (calculated or estimated from various sources)

Activity	Net annual gain or release (g/m² C)	
Humus accumulation in wet grasslands and swamps, boreal zone	0–	+10
Peat accumulation in temperate and boreal peat bogs	+20–	+80
Litter and humus accumulation in temperate forests	0–	+150
Phytomass increase in temperate forests and forest plantations	+150–	+500
Phytomass increase in early tropical secondary succession	+400–	+800
Loss of humus in mineral soils to the ocean by leaching, erosion and river discharge	0–	−5
Loss of humus from tropical podzols by blackwater formation	−60–	−80
Loss of humus in cultivated temperate steppe soils, several decades after cultivation	−10–	−150
–, first years after cultivation	−200–	−1,000
Vegetation and litter destruction by groundfires in grasslands and forests	−200–	−1,000
Loss of organic soil matter in tropical rain forests, shifting cultivation, first year after clearance	−200–	−4,000
Burning of tropical rainforest, immediate release of C	−3,000–	−15,000
For comparison: fossil fuel release in 1977, averaged over whole earth		−10
–, averaged over continents		−33

even if no sudden change in the type of vegetation is appreciable. In many of today's developed countries, there was in previous centuries a continuous thinning and degradation of the vegetation as a result of rural poverty, concentrated land ownership, primitive agricultural technology, lack of energy resources resulting in excessive fuelwood usage, and improper schemes of animal husbandry, involving foraging in forests and woodlands. In a process lasting over many decades and centuries, forests were replaced by poor woodlands and grasslands. On a greatly increased scale, the same conditions are now prevailing in many developing countries of the tropics. This may lead to a considerable net flux of C to the atmosphere, which is, however, impossible to calculate.

Historical reduction of vegetation and soil organic matter

It is beyond doubt that prior to the advent of man as an ecological agent, the earth's tropical land ecosystems used to contain more organic C than they do now, although the exact quantity removed by forest clearing, humus destruction and other activities may be open to debate. The anthropogenic losses of organic C from all land ecosystems of the earth (including non-tropical) has been calculated to be more than 700×10^{15} g (Hampicke and Bach, 1979). Combining the values of other authors (Olson et al., 1978; Buringh, 1979), this figure is raised to more than 1000×10^{15} g. The area of closed rain forests declined from an original $15-17 \times 10^{12}$ m^2 to $9-11 \times 10^{12}$ m^2 at present (Rodin et al., 1975; Persson, 1974; Sommer, 1977). Olson et al., 1978, calculated that in 1970, only 254×10^{15} g, or 47% of the preagricultural 540×10^{15} g was left in the phytomass of the tropics. The respective values given by Hampicke are 464×10^{15} g of C for the preagricultural tropics and 324×10^{15} g, or 70% of the original value, for 1977 (Hampicke, 1979c). According to Buringh, 1979, soil organic C in oxisols, ultisols and vertisols, which together make up about 50% of all tropical soils, declined from an original 461×10^{15} g to 308×10^{15} g, or only 67% thereof. It may well be that, only in the tropics, more than 300×10^{15} g of organic C - more than twice the amount released from fossil fuels - have been removed from vegetation and soils together.

A considerable portion of this loss happened in prehistoric and early historic times. For instance, in many parts of Africa north to the rain forest belt, herdsmen may have replaced dry forests by savannas (Aubréville, 1947). It is extremely unlikely, however, that all these losses date back to earlier centuries and millenia. Destructive human pressure on tropical ecosystems has never been more severe than during the last decades, and the most reasonable assumption is that at least part of the vegetation destruction and soil organic matter oxidation corresponds to human population growth. If, for instance, 150×10^{15} g of C have been released from tropical ecosystems during the past 100 years, and if the annual release has grown in an exponential way at 1-2.5% per year, the present annual release is $1.5-3.75 \times 10^{15}$ g. However imprecise in detail, considerations such as these provide strong indirect evidence for the existence of a considerable net flux of C to the atmosphere. Unless a specific reason can be found, it is just inconceivable that in earlier periods of history, with almost stable human population and very slow economic development, there was a net destruction of vegetation and soil organic matter, whereas today, with ecological deterioration being salient all over the tropics, there should be no such net flux.

Increasing atmospheric CO_2

Under laboratory conditions, with a 100% increase in atmospheric CO_2 (from 300 to 600 ppm), many species show a 40-80% increase in photosynthesis (Lemon, 1977; Strain, 1978). In this case, the biota growth factor, defined as the quotient of percent increase in photosynthesis and percent increase in atmospheric CO_2, is 0.4-0.8. Similar results are obtained with crop plants in the field, well supplied with fertilizer and water (Lemon, 1977; Strain, 1978). Some experiments with trees in natural ecosystems suggest that even under environmental stress, there can be a strong response to an enhanced atmospheric CO_2 content (Green and Wright, 1977).

On the one hand, these findings suggest that the atmospheric CO_2 increase of 14-22% (assuming preindustrial values of 290 or 270 ppm) since the industrial revolution might have stimulated photosynthesis, which in turn would have caused the C pool in terrestrial vegetation to increase, thereby forming a sink for anthropogenic CO_2 (Björkman, 1979). On the other hand, it is argued by plant physiologists that, due to worldwide deficiencies in other essential growth factors, mainly water and nitrogen, the response of almost all natural ecosystems to enhanced atmospheric CO_2 should be far below the response in the laboratory where these factors are in optimal supply (Lemon, 1977; Goudriaan and Ajtay, 1979). Biota growth factors, averaged over the entire land vegetation, in the order of 0.2-0.4, as frequently used in models (Keeling, 1973b; Keeling and Bacastow, 1977), are likely to be overestimates.

Due to the large difficulties in verifying any of these hypotheses empirically, it is not known which is the correct one. It appears justified, however, to postulate that there is at least a slight reaction of the land's vegetation to increasing atmospheric CO_2, and since the entire land vegetation is potentially affected, even such a slight reaction would lead to a net withdrawal of C from the atmosphere which might be significant in an attempt to balance the atmosphere's CO_2 budget. Assuming that the response of the entire land vegetation is only one tenth of the average response found in laboratory experiments, which is about 0.6, an atmospheric increase of 15% would lead to an additional annual net photosynthesis of $0.6 \times 0.1 \times 0.15 \times 60 \times 10^{15} = 0.54 \times 10^{15}$ g of C (global net primary production assumed to be 60×10^{15} g/year, after Ajtay et al., 1979). Though by no means proven it still seems possible that this effect results in a sink intensity of $0-1.0 \times 10^{15}$ g/year of C.

Regrowth of tropical vegetation

Net increase of C during tropical secondary succession in formerly cleared areas can amount to more than 800 g/m^2 per year (table 3). It is often argued that regrowth, in combination with delayed decomposition of partly charred plant debris, might effectively counteract net losses of C from tropical ecosystems affected by man. Although these effects should not be ignored, the net losses of tropical forest area in the past and, more likely, at present, clearly show that regrowth cannot compensate for all losses in vegetation.

The role of forests in the temperate zone

For different reasons and during different epochs, temperate and hemiboreal forests have been misused and degraded all over the world. After centuries of overlogging, tanning, charcoal production, foraging and extraction of nutrients from litter (plant residues on the forest floor) for fertilizing purposes, the reestablishment of tall forests in central Europe progressed during the 19th century. Due to a long response period, these forests may, on the whole, still be accumulating phytomass and soil organic matter. In other parts of the world this is certainly true, such as in Scandinavia, North America, the Soviet Union and China, where forest destruction, including devastating fires, continued until the first decades of this century, or even later. In contrast with the Third World countries, developed countries now have no dramatic changes in the areal extent of different kinds of land use, and forest management practices are often conducive to an increase in phytomass and soil organic matter. In Sweden, standing timber has increased by about 40% since the 1920s (Kardell, 1978). In USA forests, covering an area of about 3×10^{12} m^2, current annual production of timber is twice the amount annually harvested by logging, the difference amounting to 10×10^9 cubic feet, or roughly 75×10^{12} g of C (Clawson, 1979; Spurr and Vaux, 1976). The true net transfer of C from the atmosphere to the ecosystem is several times larger than this figure, for the merchantable timber is only a fraction – sometimes a very small fraction – of the total phytomass, including roots, branches, bark and nonmerchantable wood, accumulating in a forest. Also, part of the timber harvested and used is manufactured for long-lasting products, and there is often an appreciable accumulation of litter and soil organic matter in aggrading forests (table 3). I estimate the average annual net accumulation of C in the USA to be at least 100 g/m^2. Although this figure might be somewhat high if extrapolated to the total of circa 7.5×10^{12} m^2 of temperate forests in the world (including forest plantations), a total annual net transfer of $0.5-1 \times 10^{15}$ g of C to these ecosystems is conceivable. The phytomass increase in temperate forests, which in the USA began in about 1940 (Clawson, 1979), is probably one of the most important features of the man-influenced C cycle, and its significance has not always been sufficiently noticed. While concentrating on assessing the land vegetation's response to increased growth factors, especially CO_2, global geochemical models often fail to consider the net exchanges of C caused by natural succession in man-influenced immature forests; these would proceed even at constant atmospheric CO_2 levels.

Natural sinks

It is normally taken for granted that in the absence of man, the terrestrial biota would be in a steady state with regard to C content, as annual fluxes of CO_2 to and from the atmosphere would be of the same size. In reality, however, this is far from self-evident. About $0.4-0.5 \times 10^{15}$ g/year of C are not returned directly to the atmosphere but are transported to the sea by rivers in inorganic and organic forms (Kempe, 1979a). If the suspended organic carbon in rivers is properly included in the calculation, this value might be raised to 1×10^{15} g/year (Richey et al., 1980). The quantities originate from dissolution of carbonates and from leaching of humic substances and may, partly, form a net sink. Moreover, the size of the total C reservoir formed by the terrestrial biota responds sensitively to climatic changes. As the end of the northern hemispheric glaciation dates back only several thousand years, and considering the long response periods especially in cold climates, it is possible that the total C pool in vegetation and soils of the boreal zone has not yet reached a full equilibrium but is still growing. The most conspicuous symptom for such an accumulation is the growth of peat bogs which are accumulating $0.05-0.15 \times 10^{15}$ g/year of C (Buringh, 1979; Bramryd, 1979), but similar processes outside the peat bogs proper – in the taiga, forest tundra, tundra, in swamps, etc. – may add to this quantity. All natural sinks together are capable of withdrawing C from the atmosphere in the order of $0-0.8 \times 10^{15}$ g/year (Hampicke, 1979c).

Conclusion

Although the coarse estimates given here are not nearly as precise as the data supplied to the discussion by the atmospheric, oceanographic and geophysical sciences, they might well be relevant. The estimates for net releases of C from tropical vegetation and soils are, without exception, conservative, but still add up to several 10^{15} g/year. Even large errors in some of the estimates could hardly modify the overall conclusion that tropical land ecosystems are a net source of C for the atmosphere at present, their activity probably amounting to 30–80% of the annual release from fossil fuels. Likewise, it is probable that land ecosystems in other parts of the world (including fresh-water and estuarine ecosystems) are acting as net sinks. The amount removed from the atmosphere by these is even more difficult to estimate. From the evaluation of ecological data alone one is tempted to conclude that terrestrial sinks cannot fully compensate for the total quantity released by terrestrial sources so that, in accordance with the second hypothesis mentioned at the beginning, land ecosystems as a whole are a net source of C for the atmosphere. However, the possibility that releases and withdrawals are nearly balanced on a worldwide scale, as required by atmosphere-ocean models, cannot conclusively be ruled out. Although there are some open questions regarding the validity of atmosphere-ocean exchange models (Björkström, 1979b), these appear to be better substantiated than many other theories pertinent to the global CO_2 problem (Broecker et al., 1979; Oeschger et al., 1980). Therefore, the hypothesis that losses of CO_2 from and gains to the earth's land ecosystems are balanced on a global scale may be regarded as the hypothesis which, for the present, minimizes the amount of disagreement about all kinds of relevant knowledge on the global carbon cycle (Hampicke, 1979c, 1980).

It is doubtful that even the most careful evaluation of ecological data will by itself suffice to establish reliably the role of the land ecosystem in the global carbon cycle. Only a combined effort in all relevant research fields can solve this problem. A worldwide research programme should be initiated where evaluation of ecological field analyses and statistical data, satellite and aircraft remote sensing, analysis of stable isotopes of carbon (Stuiver, 1978; Freyer, 1979), and atmosphere-ocean models are integrated and carried out up to a point where the results of these different approaches converge.

Past and future emission of CO_2

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At present it appears that there are 2 major anthropogenic sources of CO_2: clearing of natural forests and fossil fuel burning. In his quest for agricultural land, man has removed large portions of the world's forests. During the 19th century, clearing of large areas of the temperature latitudes of the northern hemisphere occurred, and since then the process has gradually shifted southward. Tropical forests are undergoing the most rapid change now. As technology advances and the developed countries become more urbanized, there is, however, a trend toward increased reforestation. For example, since 1945 in the United States the total annual timber growth has exceeded the timber harvest (Clawson, 1979). Thus, from a combination of regrowth of forests on abandoned agricultural acreage and improved forest management procedures, the total C stored in the temperature forests of the world may be increasing. There is little doubt that some portions of the terrestrial biota provide a major source of CO_2 (as a result of the destruction of tropical forests), while other portions serve as sinks – at least on a time scale of several decades. Obtaining reliable quantitative information on either clearing or regrowth on a global scale is extremely difficult, if not impossible; extrapolating the USA case to all temperate areas obviously requires assumptions that are unfounded. Predicting future forest activity is very difficult beyond the qualitative assertion that forest management will become more extensive. When, and at what rate, destruction of natural forests will diminish is a societial unknown; obviously it must occur as the amount left uncut becomes less and less.

The second major source of CO_2 associated with man's activity is the combustion of fossil fuels. This source is easier to document, because the United Nations has developed data on each energy source for the period since 1860 (UN, 1955, 1976). Although other data sets now exist for certain fuels and/or certain portions of the world, it is customary to use these United Nations energy production data to calculate the CO_2 produced. In most cases the bases for the UN data and these other data sets are the same, and the discrepancies are minor. The UN data have the added advantage of being a consistent and continuous set so that year-to-year changes are in proper proportion.